PATENT SPECIFICATION

609,771

Application Date: March 21, 1946. No. 8818/46.

Complete Specification Left: April 3, 1947.

Complete Specification Accepted: Oct. 6, 1948.

Index at acceptance:—Classes 22, F11a(12: 14); and 83(i), F(1b: 5b: 13a5).

PROVISIONAL SPECIFICATION

Improvements relating to the Manufacture of Bladed Turbine Discs, Compressor Rotors or the like

We, POWER JETS (RESEARCH AND DEVELOPMENT) LIMITED, a British Company, of 8, Hamilton Place, London, W.1, and TRISTRAM ALLAN TAYLOR, a British Subject, of the said Company's address, do hereby declare the nature of our invention to be as follows:—

This invention relates to improvements in the manufacture of bladed turbine discs, compressor rotors or like articles, for example for use in gas turbine engines and its object is to enable complex structures of this kind to be made more easily and rapidly than hitherto. In the previously known methods of manufacture of such articles it is necessary to carry out a number of difficult and complex machining processes, and the object of the invention is to enable for example a turbine disc complete with blades or similar complex structures to be cast in one piece so that these machining processes are eliminated. Units such as axial compressors may be built up by casting the individual stages and assembling them together on a suitable shaft, or if so desired all stages may be cast as one piece.

According to the invention a bladed turbine disc, compressor rotor or like structure is made by preparing a wax model of the said structure, spraying said model with a solution containing finely ground refractory material in suspension, preparing a mould from the wax model, introducing molten metal into said mould, and subsequently spinning said mould about a vertical axis to form a centrifugal casting.

The mould may be made from refractory material and a binding liquid in the form of a liquid suspension or slurry which is poured into a container surrounding the wax model until the latter is completely immersed. The assembly is then placed on a vibrating table until the mould material has set hard. Setting may be accelerated by the addition of a suitable alkali to the mix, such as magnesium oxide or other basic oxide. After the mould has been hardened the wax model may be removed by heating the mould to melt or burn away the wax.

The suspension used for spraying the wax model is suitably chosen to give the casting a good surface finish. A suitable mixture to use may for example comprise a suspension of silica or other refractory oxide or silicate in a solution containing sodium silicate or ethyl silicate as a binder.

In applying the invention in detail one process of manufacture according to the invention as applied to a bladed turbine disc is as follows. A wax model of the turbine disc and blades is first made. This may be done by means of a master pattern from which a master mould is prepared. By injecting melted wax into this master mould and allowing the wax to set, a wax model is obtained. The complete wax model may be made at one injection into a suitable die or may be built up by welding together individual wax components made separately in dies of simpler construction, e.g. in making a wax model of a turbine the blades and disc may be made separately and afterwards welded together while located in a suitable fixture. This model is then sprayed to give it a surface coating which may for example, consist of a suspension of silica in a sodium or ethyl silicate solution.

The liquid is allowed to dry (for example at normal air temperature) and the wax model is then placed in a container which is filled with a liquid composition or slurry which when allowed to stand at room temperature or heated for several hours at a temperature of about 40—50° C. with or without the use of a vibrating table will form a hard refractory mould. The mould is then heated slowly to a temperature of about 700° C. or over so as to melt the wax and completely burn it away. The result of this procedure is to produce a refractory pre-

[Price 2/-]

cision mould which can then be used for containing molten metal.

The mould is then heated to a temperature which is adjusted to be suitable for the material being cast into it, e.g. for steels and other metals of high melting point the temperature may be raised to 1000°—1300° C. while for metals of lower melting point the mould temperature may be reduced to any desired value down to room temperature.

The molten metal is poured into the hot refractory mould which is secured to a suitable support and the latter is rapidly spun so as to create sufficient centrifugal force to fill completely the mould cavity or cavities and give the final casting its desirable metallurgical properties.

The mould is then allowed to cool until the metal has solidified and the refractory mould is then destroyed, for example by subjecting it to a few sharp blows with a hammer. The composition of the slurry composing the mould material is so chosen that the mould has sufficient mechanical strength to withstand the centrifugal forces and the impact and erosion of the molten metal, yet is not so strong that it cannot be easily removed from the casting.. A suitable composition for this purpose may for example be

Solid refractory material - 10 lbs.
Liquid - - - - - - - - 1 litre

The solid refractory material may be composed of 60% calcined fireclay "grog" and 40% silica flour, a suitable grading for which is as follows:—

Grog
B.S.S. Sieve

On 10 size mesh	- - - -	2%
Through 10 on 30	- - - -	20%
,, 30 ,, 60	- - - -	18%
,, 60 ,, 100	- - - -	17%
,, 100 ,, 170	- - - -	20%
,, 170	- - - -	Remainder

Silica Flour
All through 200 B.S.S. Sieve

The liquid may conveniently consist of:—

25% tetre ethyl silicate
50% alcohol or methylated spirit)
25% a solution of 15% concentrated hydrochloric acid in 80% aqueous alcohol.

The result of this process is to produce a bladed turbine disc having the required metallurgical properties and a good finish and complete in a single casting which may if desired be given a final additional finish, such as by mechanical or electrolytic polishing, and the turbine disc is then in suitable form for mounting in a steam or gas turbine or other prime mover.

Dated this 21st day of March, 1946.
For the Applicants:
F. J. CLEVELAND & COMPANY,
Chartered Patent Agents,
29, Southampton Buildings,
Chancery Lane, London, W.C.2.

COMPLETE SPECIFICATION

Improvements relating to the Manufacture of Bladed Turbine Discs, Compressor Rotors or the like

We, POWER JETS (RESEARCH AND DEVELOPMENT) LIMITED, a British Company, of 8, Hamilton Place, London, W.1, and TRISTRAM ALLAN TAYLOR, a British Subject, of National Gas Turbine Establishment, Whetstone, near Leicester, formerly of the said Company's address, do hereby declare the nature of our invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to improvements in the manufacture of bladed turbine discs, compressor rotors or like articles, for example for use in gas turbine engines and its object is to enable complex structures of this kind to be made more easily and rapidly than hitherto. In the previously known methods of manufacture of such articles, it is necessary to carry out a number of difficult and complex machining processes, and the object of the invention is to enable for example a turbine disc complete with blades, or a similar complex structure to be cast in one piece, so that these machining processes are eliminated. Units such as axial compressors may be built up by casting the individual stages and assembling them together on a suitable shaft, or if desired all stages may be cast as one piece.

According to the invention a bladed turbine disc, compressor rotor or like structure is made by preparing a wax model of the said structure, coating said model

with a solution containing finely ground refractory material in suspension by spraying or dipping, preparing a mould from the wax model, introducing molten metal into said mould, and subsequently spinning said mould about a vertical axis which is also the axis of said body to form a centrifugal casting.

The mould may be made from refractory material and a binding liquid in the form of a liquid suspension or slurry which is poured into a container surrounding the coated wax model until the latter is completely immersed. The assembly may then be placed on a vibrating table to remove any entrapped air bubbles, and to consolidate the mould material. Setting time is governed by the composition of the binding liquid and may be accelerated by the addition of a suitable refractory material and alkali to the mix, such as magnesium oxide or other basic compound. After the mould has been hardened the wax model may be removed by heating the mould to melt or burn away the wax.

The suspension used for coating the wax model is suitably chosen to give the casting a good surface finish. A suitable mixture to use may for example comprise a suspension of silica or other refractory oxide or silicate in a solution containing sodium silicate or ethyl silicate as a binder.

In applying the invention in detail one process of manufacture according to the invention as applied to a bladed turbine disc is as follows. A wax model of the turbine disc and blades is first made. This may be done by means of a master pattern from which a master mould is prepared. By injecting melted wax into this master mould and allowing the wax to set, a wax model is obtained. The complete wax model may be made at one injection into a suitable die or may be built up by welding together individual wax components made separately in dies of simpler construction e.g. in making a wax model of a turbine, the blades and disc may be made separately and afterwards welded together, while located in a suitable fixture. This model is then sprayed to give it a surface coating which may for example, consist of a suspension of silica in a sodium or ethyl silicate solution.

The liquid is allowed to dry (for example at normal air temperature) and the wax model is then placed in a container which is filled with a liquid composition or slurry, which when allowed to stand at room temperature or heated for several hours at a temperature of about 40—50° C. with or without the use of a vibrating table will form a hard refractory mould. The mould is then heated slowly to a temperature of about 700° C. or over, so as to melt the wax and completely burn it away. The result of this procedure is to produce a refractory precision mould which can then be used for containing molten metal.

The mould is then heated to a temperature which is adjusted to be suitable for the material being cast into it, e.g. for steels and other metals of high melting point, the temperature may be raised to 1000°—1300° C. while for metals of lower melting point the mould temperature may be reduced to any desired value down to room temperature.

The molten metal is poured into the hot refractory mould, which is secured to a suitable support and the latter is rapidly spun so as to create sufficient centrifugal force to fill completely the mould cavity or cavities and give the final casting its desirable metallurgical properties.

The mould is then allowed to cool until the metal has solidified and the refractory mould is then destroyed, for example, by subjecting it to a few sharp blows with a hammer. The composition of the slurry composing the mould material, is so chosen that the mould has sufficient mechanical strength to withstand the centrifugal forces and the impact of and erosion by the molten metal, yet is not so strong that it cannot be easily removed from the casting. A suitable composition for this purpose may, for example be

Solid refractory material	10 lbs.
Liquid	1 litre

The solid refractory material may be composed of 60% calcined fireclay "grog" and 40% silica flour, a suitable grading for which is as follows:—

Silica Flour
All through 200 B.S.S. Sieve

Grog
B.S.S. Sieve

On 10 size mesh	2%
Through 10 on 30	20%
„ 30 „ 60	18%
„ 60 „ 100	17%
„ 100 „ 170	20%
„ 170	Remainder

The liquid may conveniently consist of:—

25% tetra ethyl silicate
50% alcohol or methylated spirit)
25% a solution of 15% concentrated hydrochloric acid in 80% aqueous alcohol.

The bladed turbine disc found by the above described process may, if desired, be given a final additional finish, such as by mechanical or electrolytic polishing, before mounting it in a steam or gas turbine or other prime mover.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A method of producing a rotary bladed body, such as a bladed turbine disc or compressor rotor comprising forming a wax model of said body, spraying said model with a liquid containing finely ground refractory material in suspension, preparing a mould from the wax model, introducing molten metal into said mould and spinning said mould about a vertical axis which is also the axis of said body.

2. A method as claimed in Claim 1 wherein the liquid is a solution containing sodium or ethyl silicate containing a suspension of a refractory oxide or silicate for example silica.

3. A method as claimed in Claim 1 or 2 wherein the mould is of refractory material and is formed by pouring a liquid suspension or slurry over the coated wax model in a suitable container and subsequently setting or hardening said suspension or slurry.

4. A method as claimed in Claim 3 wherein the suspension or slurry comprises a solid refractory material and a liquid in the proportion of 10 lbs. to 1 litre respectively, the solid being composed of 60% calcined fireclay grog and 40% silica flour.

5. A method as claimed in Claim 4 wherein the liquid comprises tetra ethyl silicate, alcohol and a solution of concentrated hydrochloric acid in alcohol.

6. A method as claimed in Claim 4 wherein the liquid is composed of 25% tetra ethyl silicate, 50% alcohol and the remainder a solution of 15% concentrated hydrochloric acid in 80% aqueous alcohol.

7. A method as claimed in Claim 4, 5 or 6 wherein the silica flour all passes through a sieve of British Standard Size 200, while the grog has the following grading:—

B.S.S. Sieve	
On 10 size mesh - - - - -	2%
Through 10 on 30 - - - - -	20%
,, 30 ,, 60 - - - -	18%
,, 60 ,, 100 - - - -	17%
,, 100 ,, 170 - - - -	20%
,, 170 - - - -	Remainder

8. A method of producing a rotary bladed body substantially as hereinabove described.

9. A rotary bladed body produced by the method claimed in any one of the preceding claims.

Dated this 3rd day of April, 1947.

F. J. CLEVELAND & COMPANY,
Chartered Patent Agents,
Agents for the Applicants,
29, Southampton Buildings,
Chancery Lane, London, W.C.2.

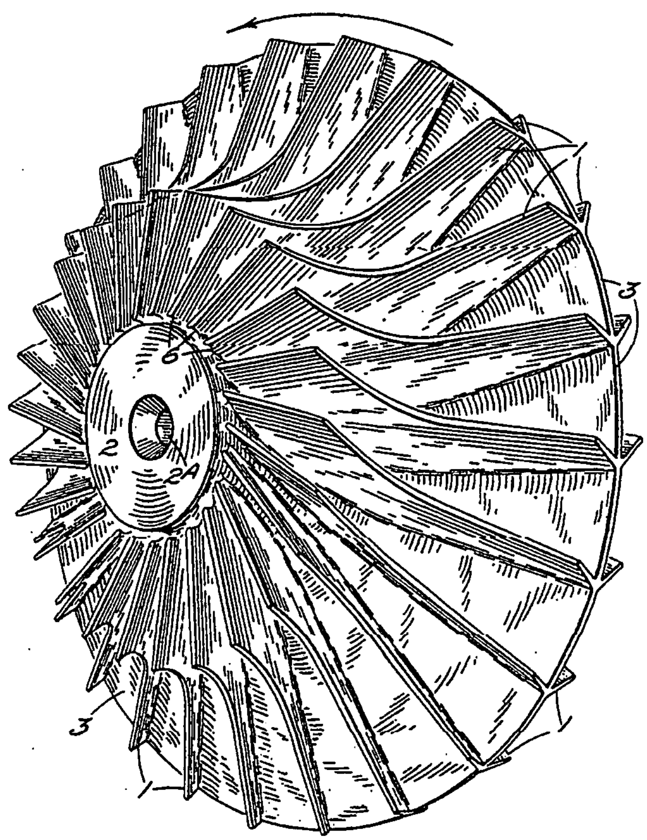
Leamington Spa: Printed for His Majesty's Stationery Office by the Courier Press.—1948.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies, price 2s. 0d. each (inland) 2s. 1d. (abroad) may be obtained.

March 29, 1949. R. D. VAN MILLINGEN ET AL 2,465,671

CENTRIFUGAL COMPRESSOR, PUMP AND THE LIKE

Filed Aug. 23, 1945 3 Sheets-Sheet 1

FIG. 1.

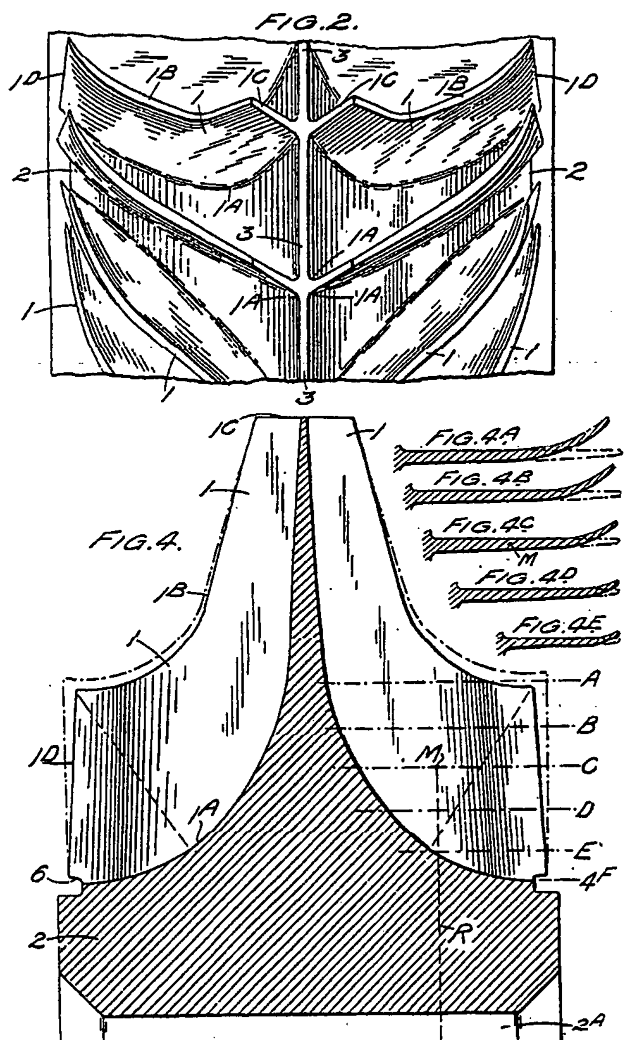


Inventors
Reuel Duncan van Millingen
Geoffrey Raignalt White
by Stevens and Davis
their attys

March 29, 1949. R. D. VAN MILLINGEN ET AL 2,465,671

CENTRIFUGAL COMPRESSOR, PUMP AND THE LIKE

Filed Aug. 23, 1945 3 Sheets-Sheet 2



Inventor
Ruel Duncan van Millingen
Geoffrey Raignault White
By Stevens and Davis
their attys.

FIG. 3.

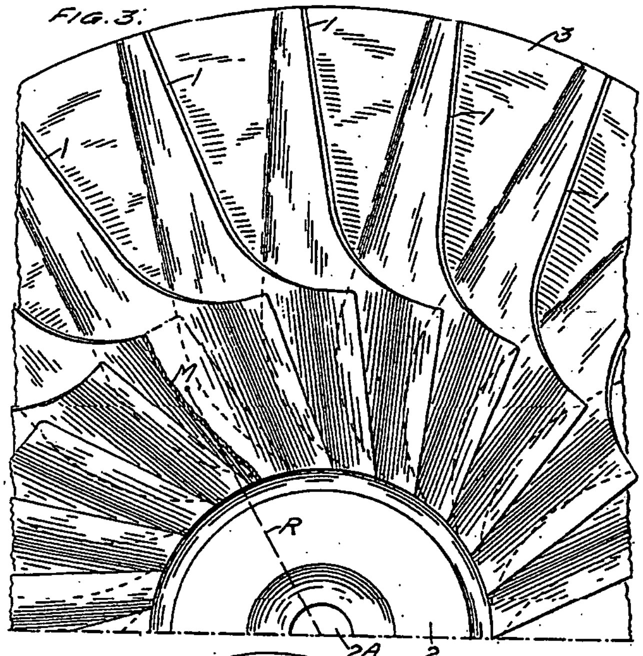
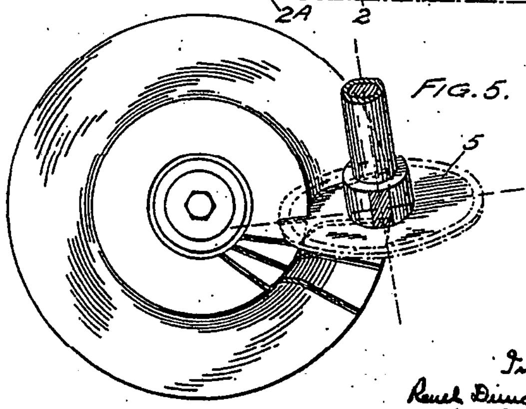


FIG. 5.



Inventor
Ronald Duncan van Millingen
Geoffrey Raignallt White
By Stevens and Davis
their attys

Patented Mar. 29, 1949 2,465,671

UNITED STATES PATENT OFFICE

2,465,671

CENTRIFUGAL COMPRESSOR, PUMP, AND THE LIKE

Reuel Duncan van Millingen, Leicester, and Geoffrey Raignallt White, Braunstone, England, assignors to Power Jets (Research & Development) Limited, London, England

Application August 23, 1945, Serial No. 612,220
In Great Britain May 10, 1944

Section 1, Public Law 690, August 8, 1946
Patent expires September 3, 1962

6 Claims. (Cl. 230—134)

This invention relates to impellers for centrifugal compressors, pumps, and the like, and whilst capable of being applied to pumps for liquid is intended primarily to apply to air compressors. The invention has for its main purpose to combine functional efficiency with practicability of manufacture, in relation to the impeller of such machines, especially when it is desired to provide machines of comparatively light weight and high rate of mass flow, which will operate with a high compression ratio per stage for the type of machine. Such attributes are especially desirable in compressors for use in aero-engine installations.

The invention is applicable both to compressors with unilateral and with bilateral intake, and especially favours the latter if maximum advantage is to be gained. Impellers with which the invention is concerned are of the type in which the vanes define channels which in the region of entry are substantially axially directed and at the periphery or region of discharge are radially directed: and consequently in which the general path of the operative fluid is directed from the axial to radial (ignoring the fact of rotation).

Aerodynamic or hydrodynamic considerations show that the change of direction of the operative fluid in the channels of the impeller of a centrifugal compressor relative to the impeller, particularly in the intake region, should be as gradual as possible if losses and undesirable phenomena are to be avoided. Change of cross-sectional area of the channels, if such change is divergent in the direction of the flow, should also be gradual and substantially more gradual around a bend than would be requisite in a straight diffuser. The angle of attack of vanes at entry should be as nearly as possible zero, referred to the relative direction of the flow to the vanes; it follows that (the vane leading edges necessarily having radial length) the leading edge regions of the vanes should have a radially decreasing angle relative to the plane of rotation because of the radial velocity gradient along the leading edge, unless the tangential or axial velocity of entering air varies radially. Mechanical and manufacturing considerations however make it difficult to give the leading edge at its least radius any angle other than that of the remainder of the vane, since it is assumed that the vanes are to be made integral with the central boss or hub of the impeller and its disc part. For high rotational speeds it is moreover desirable that the vane structure should only be subject to loads which they can comfortably withstand, and centrifugal stresses are of a high order; therefore it is mechanically desirable that the centre of mass of a vane should lie in a radius of rotation which lies within the thickness of the vane and so to design the rest of the vane that the centrifugal load due to each element of it results primarily in tensile stress, such secondary bending stress as may be inevitable being kept to the absolute minimum. The foregoing design considerations have to be compromised with ease of manufacture. The invention seeks to provide impellers which in each of these respects comes as near to the ideal as is practicable.

A centrifugal compressor or pump, especially for comparatively high mass flow and small dimensions, according to this invention has an impeller of the type stated (such as will for brevity be referred to as a centrifugal impeller) in which the substantially radial vanes, boss, and disc, are made integral, and each of these vanes is made with flat surfaces (except for the regions immediately adjacent the margins of the vane) and lies in a plane which is inclined to the axis of rotation and to the plane of rotation, at an angle which corresponds substantially to the angle of attack required of the vane at its minimum radius at the boss, or is positive in incidence at this station, by an angle between zero and the critical angle for streamline flow in the design condition of operation. Preferably each vane is also so disposed that a radial line from its centre of mass to the axis of rotation, in the plane of rotation, regarding the whole vane as an element lies in the thickness of the vane and the distribution of mass of the vane about the centre of mass is preferably such that the secondary centrifugal bending stress distribution in the vane is kept to a minimum. The vane, formed according to the foregoing, preferably has its leading edge region bent (after making the vane) forwardly in the direction of rotation or is profiled in such a fashion as to present an effective angle of attack at each radial station, corresponding substantially to the relative direction of fluid flow at entry and having regard to the rotational velocity of the leading edge at each station. Such bending, however, might be modified slightly to achieve the required passage area between adjacent pairs of vanes, but should not be so far from corresponding to a zero angle of attack, as to become critical from the streamline point of view (and it is to latitude within this compass that the word "substantially" is directed). It will be found that in design it is possible to arrange that this bending is such as to bring the centres of

mass of relatively unsupported parts of the vane, near or on radii which lie in the vane thickness, so that centrifugal bending stresses in the already bent portion, are minimised and first-order stress is all tensile.

The impeller is found to be such that the vanes can be machined by straightforward milling methods, no complicated profiling machinery being required. It may also lend itself to casting, moulding, or extrusion methods of manufacture, without the complexity of awkward re-entrant shapes in recesses of deep and narrow character.

The vanes may be formed with some extent of overhang at their leading edges; that is to say the overall axial length over the vanes is greater than that of the boss portion. In such cases the angle of the plane of a vane to the axis may be reduced to a degree according to the extent to which the overhang can be bent to take up further angle; or, the overhang may be flat and merely constitute an unbent or uncambered leading edge, in effect decreasing the pitch/chord ratio of the vanes.

The invention is preferably applied to compressors with bilateral intakes; in such cases the impeller is double-sided and symmetrical about its plane of rotation in the disc. As viewed on the tips, the vanes make a "herringbone" pattern of which the edge of the disc is the backbone.

The accompanying drawings illustrate a bilateral impeller according to the invention and also illustrate how a straightforward milling cutter method can be used for its manufacture.

Fig. 1 is a perspective view of a complete impeller.

Fig. 2 is a (fragmentary) view looking radially inwardly at the periphery.

Fig. 3 is a (fragmentary) view in axial elevation.

Fig. 4 is a half-section through the axis and is related to the sectional views 4A to 4E, taken on the lines A to E of Fig. 4.

Fig. 5 is an axial view of a blank forging, showing the attack of a milling cutter to form the vanes.

It will be seen from a general view of the drawings that the impeller is of bilateral type, that is to say it is for a compressor having double inlet eyes. The vanes on each side of a central web or disc, are so disposed that they present a "herringbone" pattern at the periphery. The vanes, the disc, and the main boss or hub of the impeller, are integral, and though it is not possible to define precisely what is "disc" and what is "boss" because these parts merge together, they are nevertheless convenient terms to use, since they are adequately descriptive in the context in which they are used.

Fig. 4 gives a good indication of the parts. The vanes 1 spring from the boss 2 and disc 3. The boss is axially bored at 2A.

Each vane 1 is initially formed (except at its margins which will be described) by flat surfaces, such as result from cutting with an edge cutter (represented at 5, Fig. 5) with a straight feed. By setting up the work (comprising an appropriately shaped blank) and the cutter 5 so that the axis of the cutter is inclined or skewed relative to the axis of the impeller, to the plane of rotation of the impeller, and to the radius of the impeller where the cut is made (as illustrated in Fig. 5), the features of the invention result. Fig. 5 shows first cuts being made; these are followed by a second series of cuts which define the second surface of each vane.

There follows further cutting to remove the material which would otherwise lie in the channels of the impeller, and further operations to remove irregularities, burrs etc. as may be necessary, also to trim up the margins and radii. The machining operations can be performed by straightforward tools, where desired, and thus no elaborate profiling needing highly specialised machine tools etc. is called for.

In the course of cutting the two surfaces of a vane, two or more cuts may be made with slight changes of the cutter angle, in order to taper the section of the vane axially or radially or both, and some blending between one so-formed flat and another, may be provided. It can be discerned from Fig. 2 for example, that the vanes are tapered towards the leading edge, in the region of a bend afterwards mentioned; as cut and before bending, the vane is made with flat surfaces.

The inner margins of the vanes, at 1A, are blended into the disc and hub by radiusing, the cutter being appropriately shaped to this end. The free margin 1B is preferably left "square" and can be formed simply by turning on a lathe. The tip 1C may be likewise left "square" or may be faired off in streamline manner. The leading edge 1D is trimmed carefully to the aerodynamically required profile.

The vanes are formed, with an overhanging leading edge, by undercutting as at 6; this permits the whole length of the leading edge to be bent to required angles of incidence, whereas the angle of the vanes at the entry end of the inner margin 1A (at 4F of Fig. 4) is of course fixed in manufacture by the skewing of the cutter. This angle which is that of the vane as a whole is selected to correspond (in the design condition of operation) with zero incidence or positive incidence within the critical angle for streamline flow.

The vanes, when formed in the manner described, can be so located with reference to the axis of the impeller, that the centre of mass (as nearly as it can be ascertained) of each vane lies in a radius from the axis of rotation which is included in the thickness of the vane. Thus if the centre of mass is the point M (in Figs. 3, 4, 4C), a radius R drawn from the axis to the point M, would be wholely within the metal thickness. This obviates any major bending loads being set up by centrifugal force. Moreover, owing to the skewed position of the vanes, the centres of mass of particles of each vane, are not very far from likewise being on contained radii, though they cannot all be exactly so, so that such bending stresses in vanes as do arise due to centrifugal force, are kept reasonably low, and all major loads are transmitted practically in tension.

In some conditions (for example where there is controlled pre-whirl or radially varying axial flow velocities of entering fluid) an impeller as so far described, i. e. with entirely flat vanes, may be practical and efficient as it stands. It is however preferred to cater for straight constant velocity axial fluid entry without pre-whirl, and this necessitates a variation of angle of incidence at the entry, at different radial stations. Such variation is afforded by bending the vanes. The nature of such bending is illustrated by the drawings and in particular by Fig. 4 and its related sectional figures which show that at lesser radius (4E) the leading edge of a vane is slightly bent forwards in the direction of rotation, and the degree of bending increases radially

outwards to that shown at 4A at the tip of the leading edge. By this means the change in peripheral velocity due to increased radius is related to the fluid path so that the incidence at entry is zero, or is positive within the critical angle. At the location 4F however, the vane cannot be bent because its margin is not free, hence the above-mentioned fact that the angle of the whole vane is defined by the incidence required at its minimum radius.

The bending of the vanes is preferably by manipulation whilst hot, use being made of blocks or formers appropriately contoured, and temporarily held in the channels between one vane and the next, in known manner. Such bending as that shown has the incidental advantage that it brings the centre of mass of the least well supported part of the vane, i. e. the region of the outer part of the leading edge, nearer the condition where it lies on a contained radius.

In putting the invention into practice, it may be noted that turning operations to finish the free margin, or on the leading edges, should be performed with the vanes well damped against vibration; this can be accomplished by casting the whole impeller solid in wax prior to turning, and turning off both metal and wax, subsequently melting off the remaining wax.

It will be seen that the double sided impeller has its vanes so arranged that they are raked forwards in the intended direction of rotation, shown by the arrow in Fig. 1, that is to say so that the free margins 1B and 1D lead the margin 1A.

We claim:

1. A centrifugal fluid impeller comprising integral boss, disc, and vanes, each of said vanes comprising a radially disposed main portion and an entry portion forming a continuation of the main portion, the vanes defining curved channels substantially axially directed at the fluid entry region and substantially radially at the fluid discharge region and each of said vanes having flat surfaces except at the margin of the entry portion and lying in a plane which is inclined to the plane of rotation of the impeller at an angle which corresponds substantially to the angle of attack required of the entry portion of the vane at its minimum radius in the design condition of operation.

2. An impeller according to claim 1 in which the leading edge region of each vane at the eye of the impeller is bent towards the direction of rotation so as to present an angle of attack at each radial station corresponding substantially to the relative direction of fluid flow at entry in the design condition of operation having regard to the velocity of the leading edge at each such station.

3. A centrifugal fluid impeller comprising integral boss, disc, and vanes, each of said vanes comprising a radially disposed main portion and an entry portion forming a continuation of the main portion, the vanes defining curved channels substantially axially directed at the fluid entry region and substantially radially at the fluid discharge region and each of said vanes having flat surfaces except at the margin of the entry portion and lying in a plane which is inclined to the plane of rotation of the impeller at an angle which corresponds to an angle of attack of the entry portion of the vane at its minimum radius which is positive but less than the critical angle for streamline flow in the design condition of operation.

4. An impeller according to claim 3 in which the leading edge region of each vane at the eye of the impeller is bent towards the direction of rotation so as to present an angle of attack at each radial station corresponding substantially to the relative direction of fluid flow at entry in the design condition of operation having regard to the velocity of the leading edge at each such station.

5. A centrifugal fluid impeller comprising integral boss, disc, and vanes, each of said vanes comprising a radially disposed main portion and an entry portion forming a continuation of the main portion, the vanes defining curved channels substantially axially directed at the fluid entry region and substantially radially at the fluid discharge region and each of said vanes having flat surfaces except at the margin of the entry portion and lying in a plane which is inclined to the plane of rotation of the impeller at an angle which corresponds to an angle of attack of the entry portion of the vane at its minimum radius which is within the range from zero to the critical angle for streamline flow in the design condition of operation, and the approximate center of mass of each vane lying in a radius which is included in the thickness of the vane when struck from the axis of rotation.

6. An impeller according to claim 5 in which the leading edge region of each vane at the eye of the impeller is bent towards the direction of rotation so as to present an angle of attack at each radial station corresponding substantially to the relative direction of fluid flow at entry in the design condition of operation having regard to the velocity of the leading edge at each such station.

REUEL DUNCAN VAN MILLINGEN.
GEOFFREY RAIGNALLT WHITE.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,546,323	Spowage	July 14, 1925
2,398,203	Browne	Apr. 9, 1946
2,399,852	Campbell et al.	May 7, 1946

Certificate of Correction

Patent No. 2,465,671. March 29, 1949.

REUEL DUNCAN van MILLINGEN ET AL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

In the heading to the printed specification, line 9, foreign filing date, for "May 10, 1944" read *September 3, 1942*;

and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 16th day of August, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.